Aviation Weather Meteorology for Pilots

Chapter 6

Section A

Basic Weather Theory

The Atmosphere

- Mixture of gases surrounding the earth
- Fairly uniform in proportions up to approx. 260,000 feet
- Divided into layers that are defined by other criteria

The Atmosphere

- Troposphere
- Tropopause
- Stratosphere
- Mesosphere
- Thermosphere

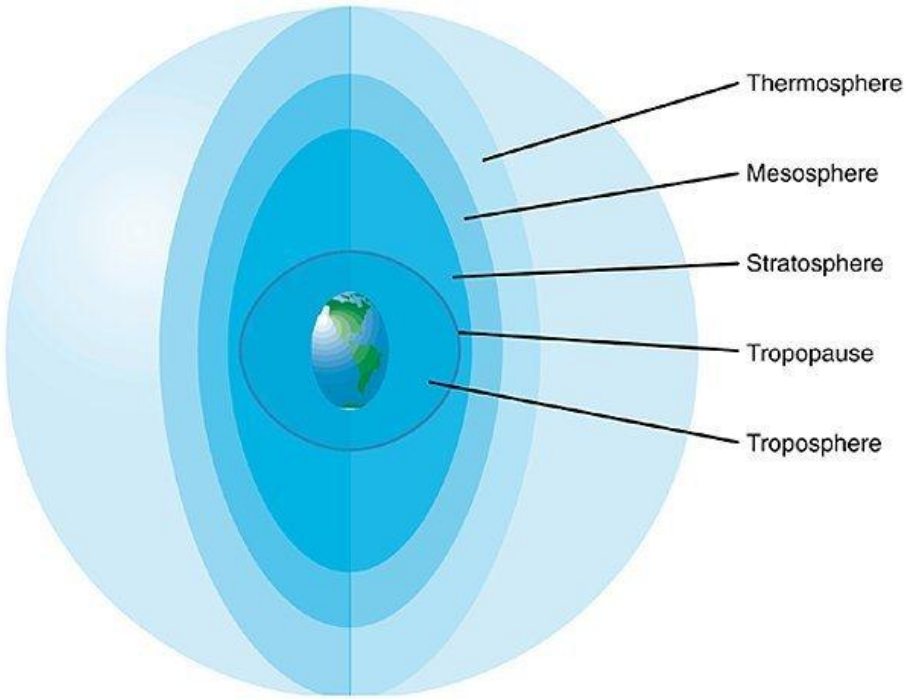

FIG 6-2

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The Atmosphere

- Troposphere
  - Surface to approx. 36,000 feet
    - Higher in summer than winter
    - Higher at equator than poles
  - Where most of the weather is
- Tropopause – top of troposphere, jet stream, turbulence, top of thunderstorms
- Stratosphere – to approx. 160,000 feet
- Mesosphere and Thermosphere

Composition of the Atmosphere

- Gases
  - Nitrogen 78%
  - Oxygen 21%
  - Other 1%
  - Water vapor 0% to 4%
- Pollutants

Atmospheric Circulation

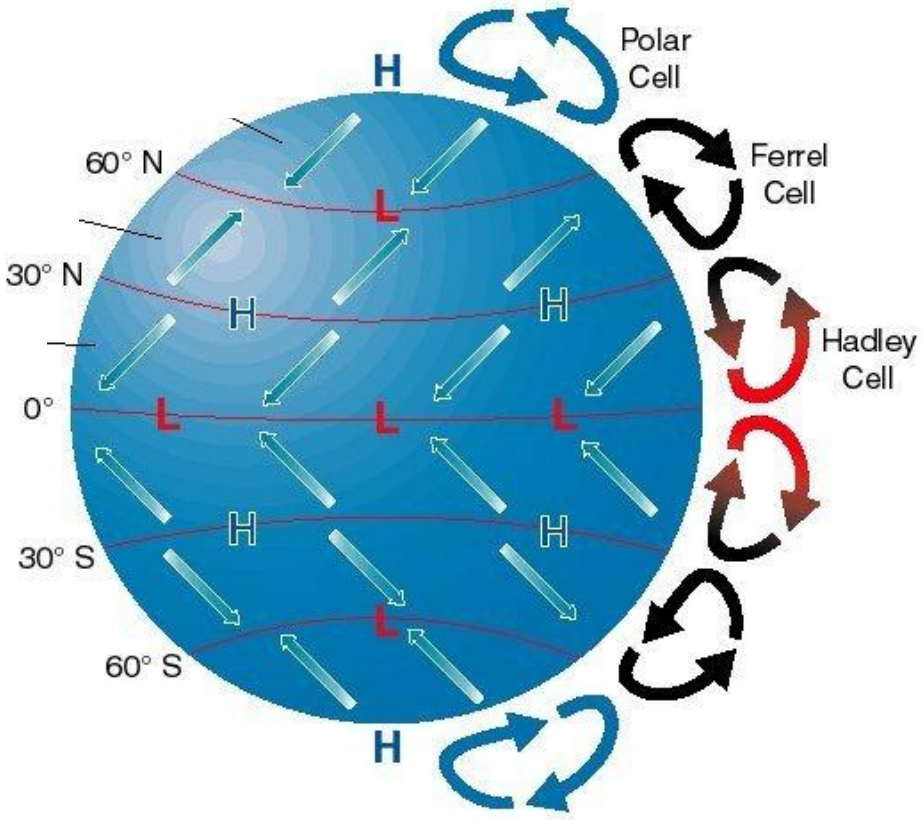
- Why is there movement of the air?
  - Atmosphere fixed to earth by gravity
  - Rotates with earth
- What upsets the equilibrium?
  - Unequal temperatures at the earth's surface

Circulation - theory

- Temperature is affected by exposure to sun
  - Length of time – summer versus winter
  - Angle at which sun strikes the surfaces – equator versus poles
- Air compensates for unequal heating by convection
  - Warmer air is less dense, rises - equator
  - Cooler air is more dense, sinks - poles
  - and replaces warmer air by flowing to equator

Circulation - reality

- Three-cell pattern
  - Hadley Cell
  - Ferrel Cell
  - Polar Cell



Atmospheric Pressure

- Unequal heating causes
  - Changes in air density
  - Circulation
  - Results in pressure changes
- Altimeter settings are different in different locations

On the Weather Maps

- Isobars
  - Lines connecting points of equal pressure
- Pressure gradient – change in pressure over distance
  - Close together or widely spaced isobars indicate strong or weak gradient

Isobars Identify Pressure Systems

- High pressure system
- Low pressure system
- Ridge
- Trough
- Col

Air Flow

- From cool, dense air of high pressure
- To warm, less dense air of low pressure

- Pressure gradient force
  - Strong pressure gradient (isobars close together) = strong wind
  - Weak pressure gradient (isobars far apart) = light wind

Coriolis Force

- Air does not go in a straight line directly from high pressure to low pressure

- Rotation of the earth causes path to deflect
  - To right in northern hemisphere
  - To left in southern hemisphere
  - No deflection at equator, most deflection at poles
  - The greater the speed the greater the deflection

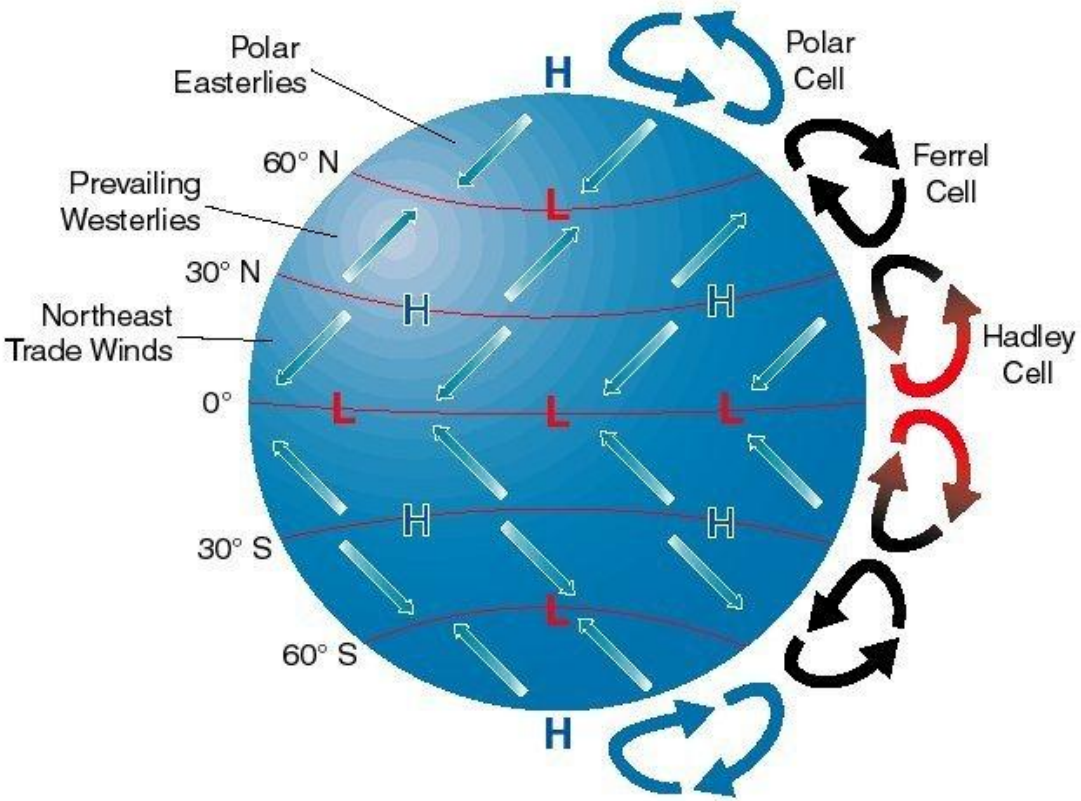
Coriolis Force

- Deflection continues until Coriolis Force and Pressure Gradient Force are equal
- Air flows parallel to isobars
- Clockwise flow around a high pressure area
- Counterclockwise around a low pressure area

Frictional Force

- Friction slows air near surface of earth
- Less Coriolis force because of slower speed of air
- Pressure gradient force is greater and air flows toward low pressure

Global Wind Patterns



Local Wind Patterns

- Wind patterns are affected by:
  - Terrain variations
  - Water
- Warmer air rises - cool air replaces warm air
  - Same as global patterns – smaller scale

Sea Breeze

- Day time heating of land
- Causes air to rise
- Cooler air from over water flows in to replace warmer air
- Return flow above sea breeze
- 10 to 20 knots
- 1,500 to 3,000 feet AGL

Land Breeze

- Land cools faster than water at night
- Reverse of daytime sea breeze
- Temperature contrasts less at night than during day so land breeze not as strong
- 1,000 to 2,000 feet AGL

Valley Breeze

- Mountain slopes heated by sun which heats adjacent air
- Warmed air flows up the valley
- 5 to 20 knots
- Maximum winds several hundred feet above surface

Mountain Breeze

- At night, terrain cools
- Becomes cooler than the air
- Pressure gradient reverses
- Air flows down the slopes and valley
- 5 to 15 knots, max 25 knots

Katabatic Wind

- Downslope wind
- Stronger than mountain breeze
- Either warm or cold

Cold Downslope Winds

- Over areas of ice or snow air becomes extremely cold
- Shallow dome of high pressure forms
- Pressure gradient force pushes cold air through gaps in mountains
- If through a narrow canyon, speeds can exceed 100 knots
- Named in some locations – bora (Croatia), mistral (France), Columbia Gorge wind (US)

Warm Downslope Wind

- Warm airmass moving over mountains can form trough of low pressure on lee side
- Causes downslope wind to develop
- As descends, compresses and warms
- Can increase over 20º in an hour
- 20 to 50 knots, as much as 100 knots
- Named – Chinook (eastern slopes of Rockies), foehn (Alps), Santa Ana (So. Calif)

Meteorology for Pilots

Chapter 6

Section B

Weather Patterns

Atmospheric Stability

- Stability – resistance to vertical motion
- Stable atmosphere makes vertical motion more difficult
- Generally smooth air
- Unstable air – turbulent, rising air, large vertical movement
- Significant cloud development, hazardous weather

Adiabatic Heating/Cooling

- Air moving up – expands due to lower pressure
- Air moving down – compressed, high pressure
- As pressure changes so does temperature
- Process is adiabatic heating (compression) or cooling (expansion

Lapse Rate

- Lapse rate – rate of temperature decrease with increase in altitude
- Average is 2ºC (3.5ºF) per 1,000 feet

Water Vapor and Lapse Rate

- Water vapor is lighter than air
  - Moisture decreases air density – causes air to rise
  - Less moisture – air is more dense – air descends
- Moist air cools at a slower rate than dry air
- Dry adiabatic lapse rate is 3ºC (5.4ºF) per 1,000’
- Moist adiabatic lapse rate is

  1.1ºC to 2.8ºC (2ºF to 5ºF) per 1,000’

Temperature and Moisture

- Combined, determine the stability of air
- Warm, moist air = greatest instability
- Cold, dry air = greatest stability

- Lapse rate can be used to determine the stability of the atmosphere

Temperature Inversions

- Temperature usually decreases with altitude
- Inversion is when temperature increases with altitude
- Usually in shallow layers
- Near surface or at higher altitudes
- Lid for weather and pollutants
- In stable air with little or no wind and turbulence
- Visibility usually poor

Temperature Inversion

- Clear, cool night, calm wind
- Terrestrial radiation
  - Ground cools, lowers the temperature of air near ground
- Cooler layer of air next to ground

Frontal Inversions

- Cold front
  - Cool air forced under warm air
- Warm front
  - Warm air rides up over cold air

Moisture

- In terms of flight hazards
  - Very moist air – poor or severe weather can occur
  - Dry air – weather will usually be good

State of moisture

- Solid, Liquid, Gas

- Evaporation
- Condensation
- Sublimation
- Deposition
- Melting
- Freezing

Latent Heat

- Extra heat in changing state – either absorbed or released
  - 32º water to 32º ice
- Every physical process of weather is accompanied by a heat exchange
- Page 6-19, Latent heat diagram

Humidity

- Moisture in the air
- Relative humidity
  - Actual amount of moisture in air compared to total amount that could be at that temperature
- Amount of moisture in the air depends on air temperature

Dewpoint

- Temperature to which air must be cooled to become saturated – can hold no more water

- Calculate cloud bases

$$\frac{\text{Temp } ^{o}\text{F} - \text{Dewpoint } ^{o}\text{F}}{4.4\ ^{o}\text{F}} \times 1{,}000$$

Dew and Frost

- Surface cools to temp below the dewpoint of surrounding air
  - Dew if dewpoint is above freezing – water vapor condenses
  - Frost if dewpoint is below freezing – water vapor changes directly to ice

Frost and Airplanes

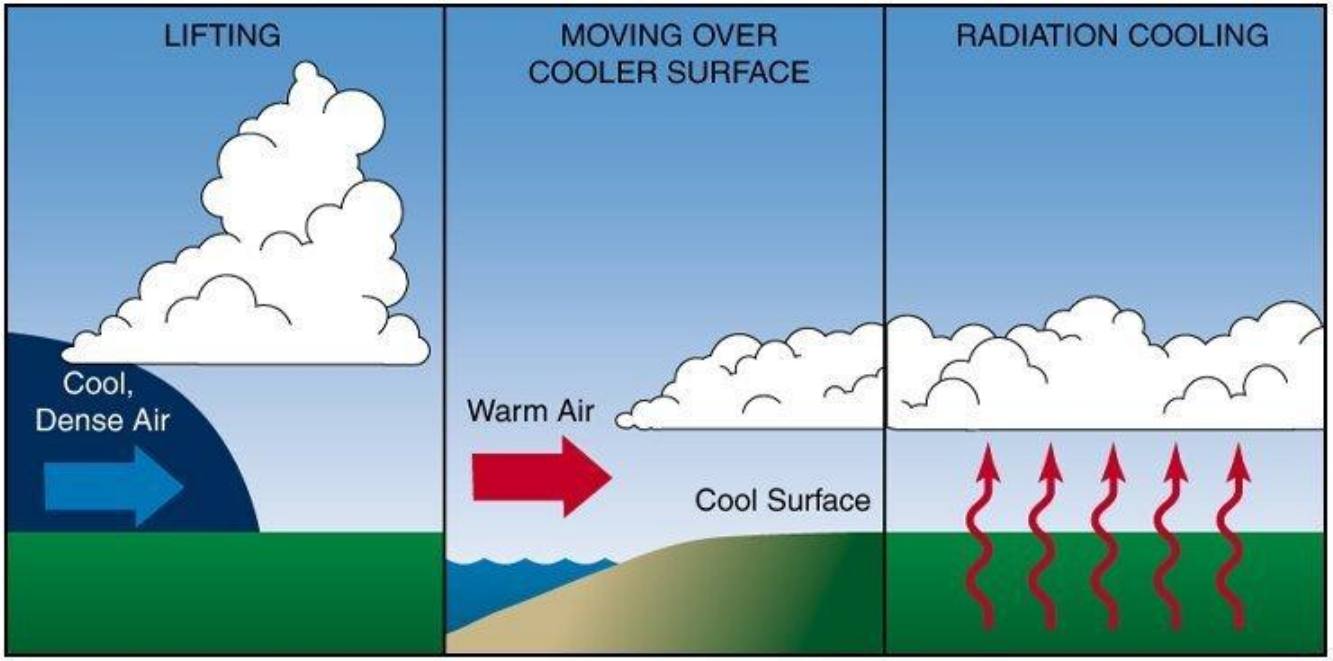
- Frost
  - Spoils smooth surface of airfoil
  - Spoils the smooth airflow over wings
  - Decreases lift
  - Increases drag

- Thou shall not fly an airplane with frost on it.

Clouds

- Air cools to saturation point
- Condensation and sublimation changes vapor into visible moisture
- Clouds, fog (clouds near surface)
- Very small droplets or ice crystals
- Condense or sublimate onto small particles of solid matter in the air – condensation nuclei

Cooling of Air



Clouds and Fog

- Anticipate by noting temperature/dewpoint spread

- Less than 4ºF (2ºC) of spread and decreasing
  – favorable for fog, clouds

Types of Clouds

- Grouped by families according to altitude
- Low, fog
- Middle
- High
- Clouds with vertical development

Low Clouds

- Surface to about 6,500 feet
- Stratus
  - Layered, stable, uniform appearance, cover wide area
- Nimbostratus
  - Nimbus means rain producing
  - Widespread areas of rain, thick layer, heavy icing if below freezing
- Stratocumulus
  - White, puffy clouds

Fog

- Low cloud
- Base within 50 feet of the ground
- Ground fog if less than 20 feet deep
- Classified by way forms
  - Radiation fog – clear, calm, humid nights
  - Advection fog – warm, moist air moves over cooler surface
  - Upslope fog – moist, stable air forced up sloping land
  - Steam fog – cold, dry air moves over warmer water, turbulence and icing hazard

Middle Clouds

- 6,500 to 20,000 feet AGL
- Altostratus
  - Flat, dense, uniform color, min. turbulence, mod. ice
- Altocumulus
  - Patchy, uniform appearance, over wide area, often from altostratus clouds breaking up, light turbulence

High Clouds

- Above 20,000 feet AGL
- Cirrus
  - Wispy, indicate stable air, white, patches or bands
- Cirrostratus
  - Thin, white, long bands or sheets, low moisture content
- Cirrocumulus
  - White, patchy, look like cotton, light turbulence

Clouds with Vertical Development

- Cumulus
  - In convective currents from heating of earth's surface, flat bottoms, dome-shaped tops, fair weather cu's, turbulence, little icing or precip
- Towering cumulus
  - Large mounds of cotton, deep area of unstable air, heavy turbulence, icing, pre-thundestorm
- Cumulonimbus
  - Thunderstorms, large, vertically developed, very unstable air, large amounts of moisture, heavy turbulence, icing, hail – many flight hazards

Precipitation

- Water, liquid or solid, that falls from the atmosphere and reaches the ground

- Aviation problems
  - Visibility
  - Engine performance
  - Increased braking distance
  - Wind – shift direction, velocity
  - Icing

Precipitation Causes

- Need
  - Saturation of atmosphere
  - Growth of water or ice particles to point where atmosphere can not support them

Precipitation Causes

- Condensation/deposition
- Coalescence

- Slow and inefficient

Precipitation Causes

- Super-cooled water droplets
- H_2O in liquid form to temperatures as low as -40ºC
- Water vapor from these droplets cause ice crystals to grow more quickly

Types of Precipitation

- Drizzle <.02 inches in diameter
- Rain, rain showers
- Virga
- Precipitation induced fog
- Freezing drizzle, freezing rain – like drizzle and rain but freeze on contact with ground or objects

Types of Precipitation

- Ice pellets
- Hail
- Snow
- Snow grains
- Fallstreaks or mare’s tails

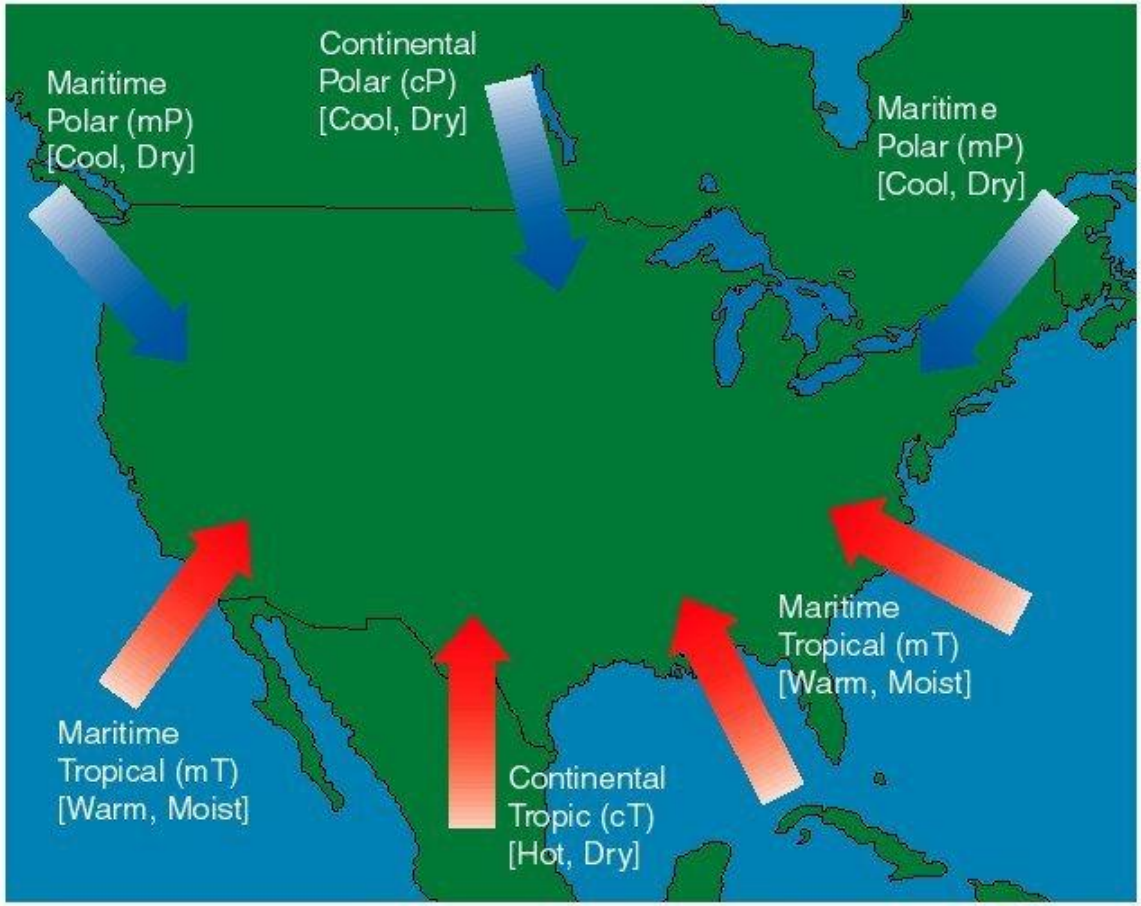
Airmasses

- Large body of air
- Uniform temperature
- Uniform moisture content
- Several hundred miles across
- Forms where air remains stationary for several days

Source Regions

- Where air tends to stagnate
- Semi-permanent areas of high pressure
  - Polar
  - Tropical
  - Continental
  - Maritime

Source Regions



Stable Air Characteristics

- Smooth
- Layered/stratiform clouds
- Restricted visibility
- Widespread clouds
- Steady rain or drizzle

Unstable Air Characteristics

- Cumuliform clouds
- Showers
- Turbulence
- Good surface visibility

Modification

- After source region, airmass takes on characteristics of area over which it moves
- Degree of change
  - Depends on speed of airmass
  - Nature of area it moves over
  - Temperature difference
  - Depth of airmass

Warming from Below

- Causes vertical movement of air
- Causes instability
- Lake effect

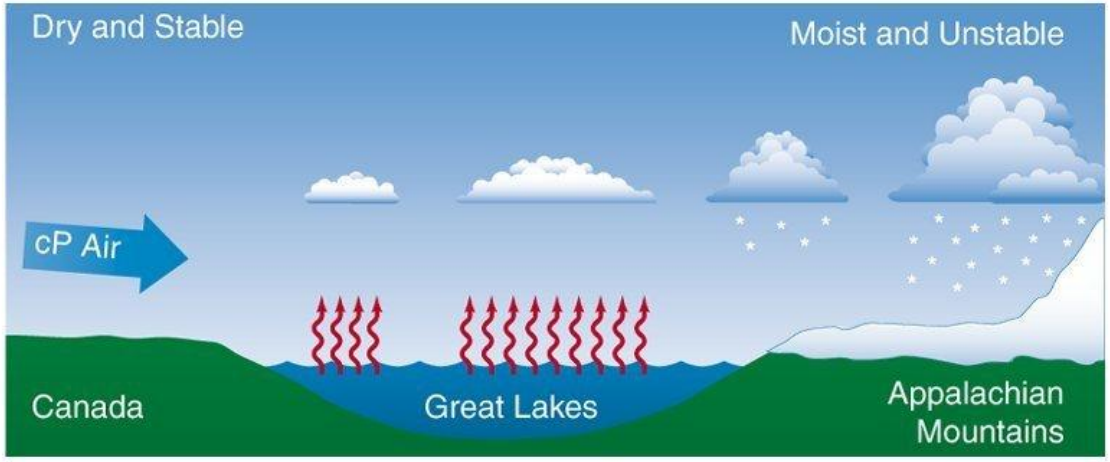


FIG 6-32

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Cooling from Below

- Vertical movement is inhibited
- Stability of air is increased
- Enough moisture – fog will develop
- Temperature inversion
  - Low ceilings
  - Poor visibility

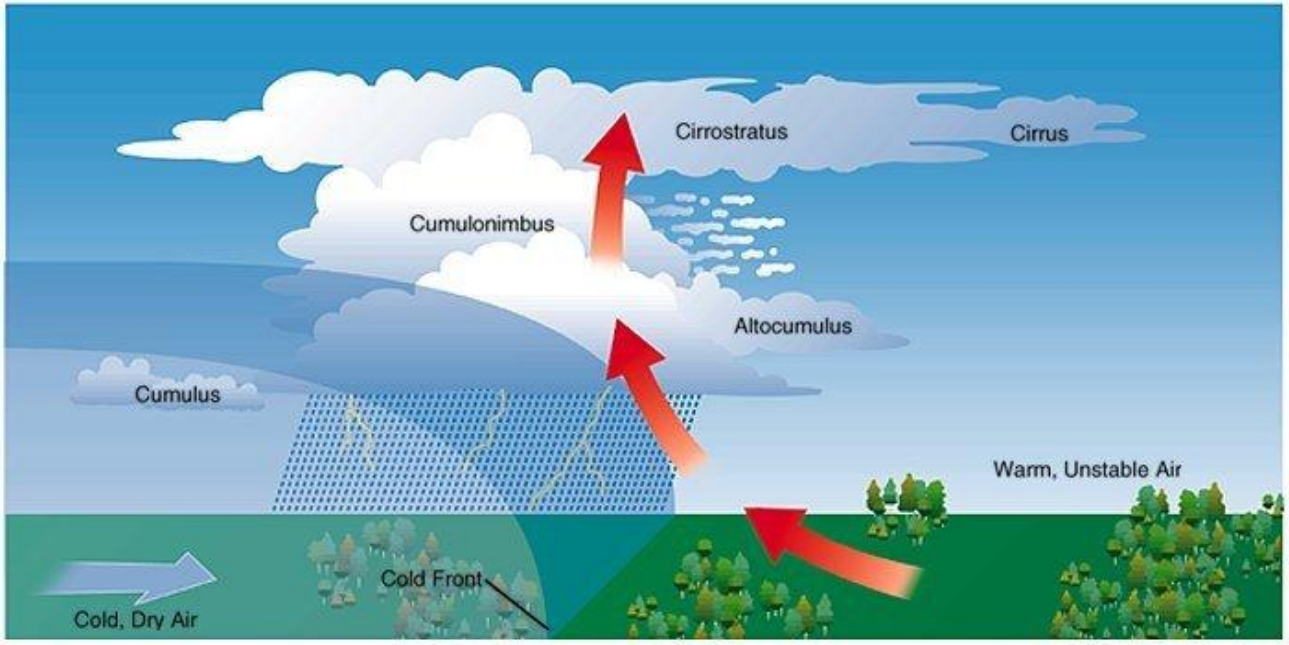
Fronts

- Boundaries between airmasses
- Cold front
- Warm front
- Stationary front
- Occluded front

Discontinuities

- Or how do you know when a front passes by?
  - Temperature – more pronounced at surface
  - Wind – direction and possible speed
  - Pressure – lowest pressure directly over front

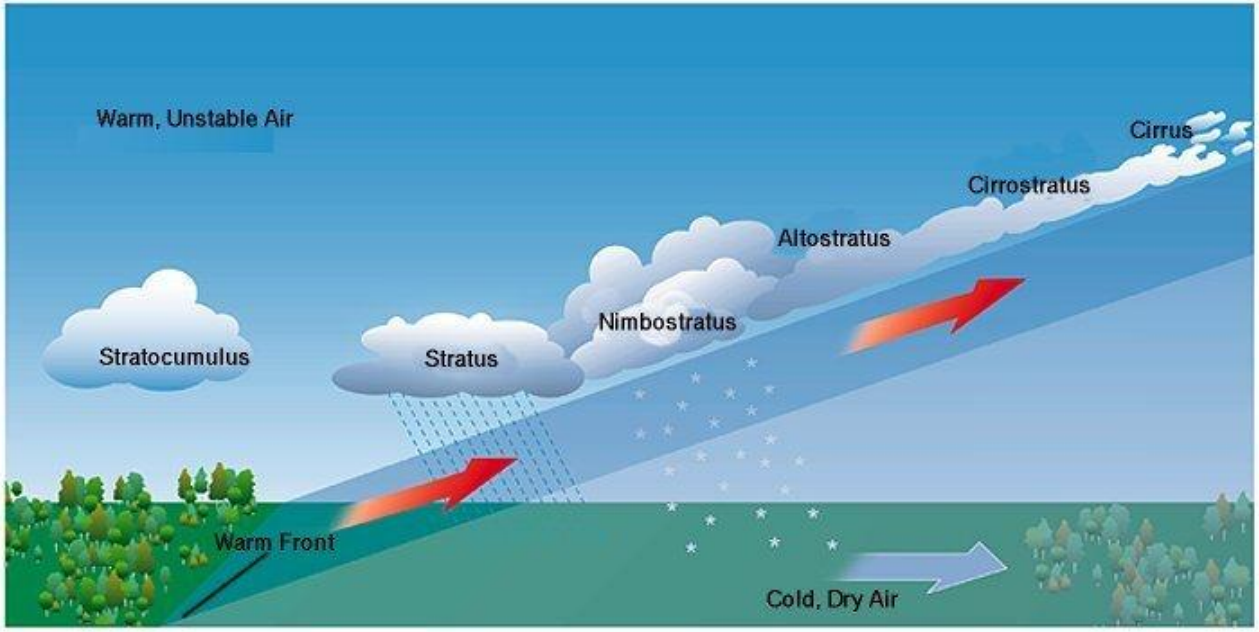
Cold Front


Cirrostratus
Cirrus
Cumulonimbus
Altocumulus
Cumulus
Warm, Unstable Air
Cold Front
Cold, Dry Air

Cold Front Weather

TYPICAL COLD FRONT WEATHER			
	Prior to Passage	During Passage	After Passage
Clouds	• Cirriform • Towering cumulus and/or cumulonimbus	• Towering cumulus and/or cumulonimbus	• Cumulus
Precipitation	• Showers	• Heavy showers • Possible hail, lightning, and thunder	• Slowly decreasing showers
Visibility	• Fair in haze	• Poor	• Good
Wind	• SSW	• Variable and gusty	• WNW
Temperature	• Warm	• Suddenly cooler	• Continued cooler
Dewpoint	• High	• Rapidly dropping	• Continued drop
Pressure	• Falling	• Bottoms out, then rises rapidly	• Rising

Warm Front


Warm, Unstable Air
Cirrus
Cirrostratus
Altostratus
Nimbostratus
Stratocumulus
Stratus
Warm Front
Cold, Dry Air

Warm Front Weather

TYPICAL WARM FRONT WEATHER			
	Prior to Passage	During Passage	After Passage
Clouds	• Cirriform • Stratiform • Fog • Possible cumulonimbus in the summer	• Stratiform	• Stratocumulus • Possible cumulonimbus in the summer
Precipitation	• Light-to-moderate rain, drizzle, sleet, or snow	• Drizzle, if any	• Rain or showers, if any
Visibility	• Poor	• Poor, but improving	• Fair in haze
Wind	• SSE	• Variable	• SSW
Temperature	• Cold to cool	• Rising steadily	• Warming, then steady
Dewpoint	• Rising steadily	• Steady	• Rising, then steady
Pressure	• Falling	• Becoming steady	• Slight rise, then falling

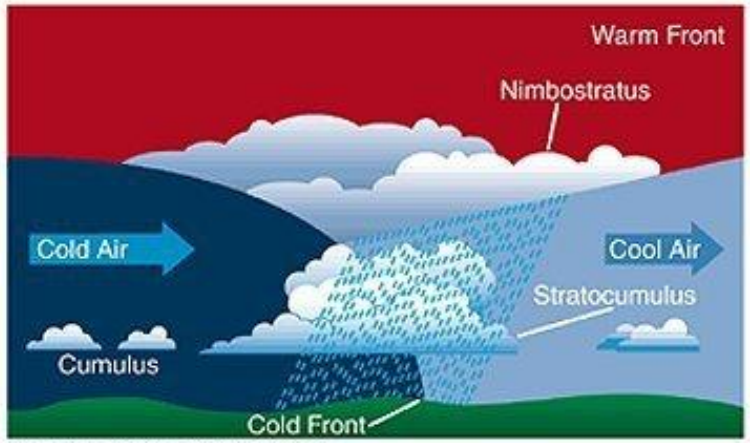
Stationary Front

- Opposing airmasses relatively balanced
- Stay in place for several days
- Weather is a mixture of both warm and cold fronts

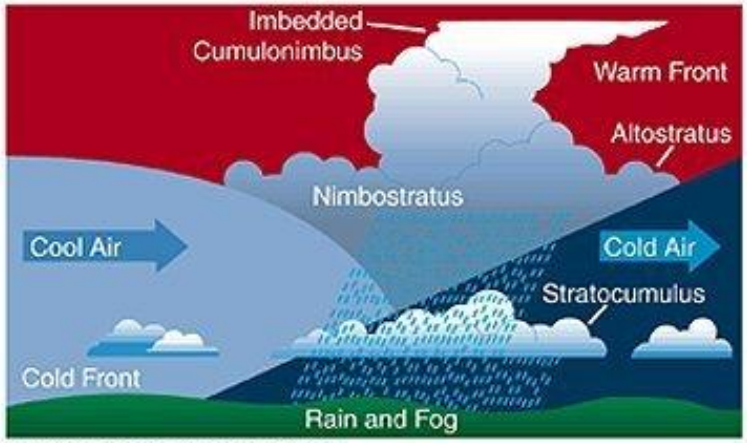
Occluded Front

- Fast moving cold front catches up with slow moving warm front
- Cold front occlusion
  - Cold front colder than air ahead of warm front
- Warm front occlusion
  - Air ahead of warm front is colder than air with cold front

Occluded Fronts



COLD FRONT OCCLUSION



WARM FRONT OCCLUSION

Occluded Front Weather

TYPICAL OCCLUDED FRONT WEATHER			
	Prior to Passage	During Passage	After Passage
Clouds	• Cirriform • Stratiform	• Nimbostratus • Possible towering cumulus and/or cumulonimbus	• Nimbostratus • Altostratus • Possible cumulus
Precipitation	• Light-to-heavy precipitation	• Light-to-heavy precipitation	• Light-to-moderate precipitation, then clearing
Visibility	• Poor	• Poor	• Improving
Wind	• SE to S	• Variable	• W to NW
Temperature	• Cold Occlusion: Cold to Cool • Warm Occlusion: Cold	• Cold Occlusion: Falling • Warm Occlusion: Rising	• Cold Occlusion: Colder • Warm Occlusion: Milder
Dewpoint	• Steady	• Slight drop	• Rising, then steady
Pressure	• Falling	• Becoming steady	• Slight drop; however, may rise after passage of warm occlusion

Meteorology for Pilots

Chapter 6

Section C

Weather Hazards

Thunderstorms

- Needed for development of thunderstorms
  - Unstable conditions
  - Lifting force
  - High moisture levels

Thunderstorms – Two Types

- Airmass
  - Scattered
  - Short-lived
  - Rarely have large hail or strong winds
- Severe
  - 50 knot winds or more
  - Hail ¾ inches diameter
  - Tornadoes

T-storms

- Single-cell – an hour
- Super-cell – may last two hours
- Multi-cell – cluster of t-storms at different stages, interact to last longer than individual cells would

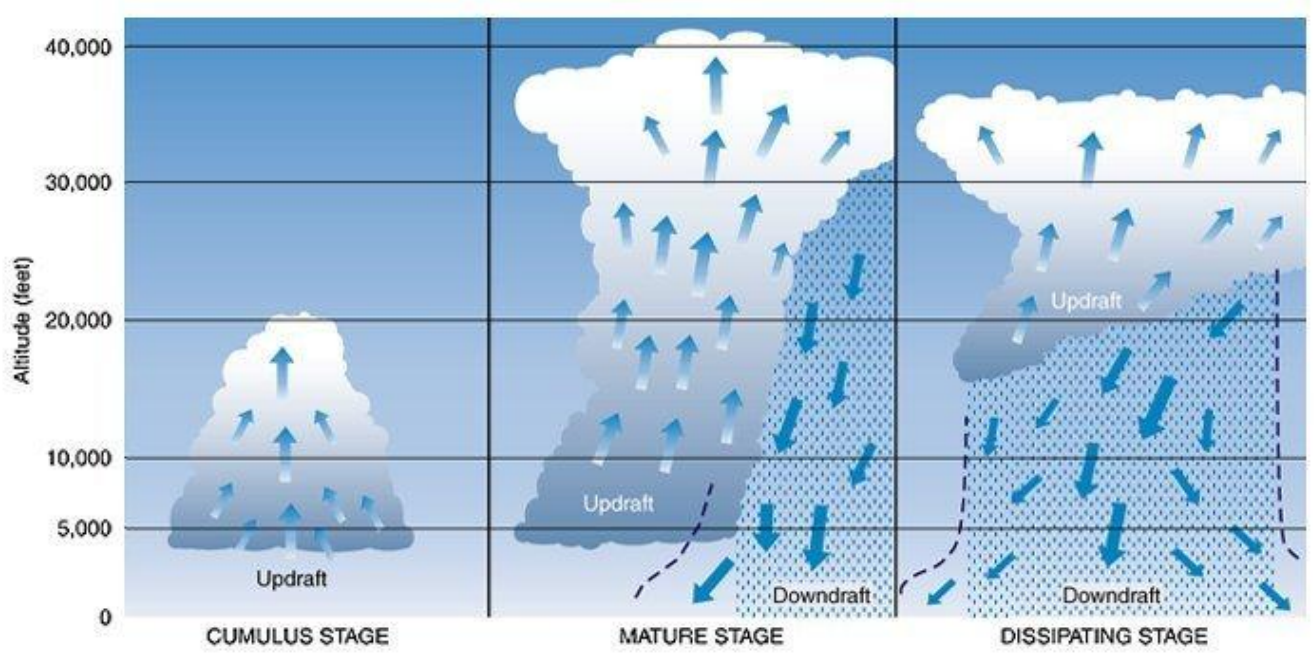
T-storms

- Squall line – non-frontal, often 50 to 300 miles ahead of fast-moving cold front, continuous line, most severe conditions (winds, hail, tornadoes)

- Frontal thunderstorms – with frontal activity
  - Warm front – obscured, with showery precip
  - Cold front – visible line
  - Occluded front – depends on conditions

Thunderstorm Life Cycle

- Three stages of a thunderstorm



Cumulus Stage

- Lifting action begins the vertical movement
- Continuous updrafts
- Condensation creates clouds, releases latent heat which continues vertical development
- No precipitation falls
- 3000’/minute updrafts
- Grows rapidly into towering cumulus
- 15 minutes

Mature Stage

- Precipitation begins to fall – signals mature stage
- Warm updrafts and cool precipitation induced downdrafts = severe turbulence
- Gusty surface winds and wind shear – gust front and roll cloud
- Top as high as 40,000’ – spreads out horizontally forming anvil (points in approx. direction of storm’s movement)

Dissipating Stage

- 15 to 30 minutes after precip begins
- Characterized by downdrafts
- Weakens
- Stratiform appearance, gradually dissipates
- Anvil lasts longer – ice cloud

Upper-level Winds and T-storms

T-storm Hazards – Turbulence

- Turbulence – cumulonimbus clouds are the most turbulent clouds
  - Between updrafts and downdrafts in the t-storm
  - Low-level turbulence where downdrafts spread out at the surface

T-storm Hazards – Lightning

- Lightning – always associated with t-storms
  - In-cloud
  - Cloud-to-cloud
  - Cloud-to-ground
  - Cloud-to-clear air
  - 300,000 volts per foot, 50,000ºF
- Rarely harm crew or substantially damage plane
  - Can cause temp. loss of vision, puncture aircraft skin, damage electronic nav. and comm. equipment

T-storm Hazards – Hail

- Occurs at all altitudes
- In or outside of clouds
- Can be thrown downwind
- Can do major damage to aircraft

T-storm Hazards – Tornadoes

- Funnel cloud descends from bottom of cloud
- Touching ground – tornado
- Touching water – waterspout
- Winds can exceed 200 knots

Turbulence

- Turbulence in and near thunderstorms
- Low-level turbulence
- Clear air turbulence
- Mountain wave turbulence

- What to do –
  - In flight, slow to maneuvering speed, maintain level flight attitude
  - On approach, consider power-on approach with slightly higher than normal approach speed

Low-level Turbulence

- Below 15,000’
- Usually due to surface heating or friction
- Four types:
  - Mechanical
  - Convective
  - Frontal
  - Wake

Mechanical Turbulence

- Obstacles (building, terrain) interfere with normal wind flow
- Wind forms eddies when it blows around trees, hangars, etc.
- Produced downwind of obstructions

Convective Turbulence

- Thermal turbulence
- Daytime, fair weather
- Either cold air moving over warm surface or when ground is heated by the sun
- 200 to 2,000 f.p.m. updrafts
- Towering cumulus clouds indicate presence of convective turbulence
- Capping stable layer above cumulus clouds, haze or dust

Frontal Turbulence

- In the narrow zone just ahead of a fast-moving cold front
- Up to 1000 f.p.m.
- Moderate or greater turbulence

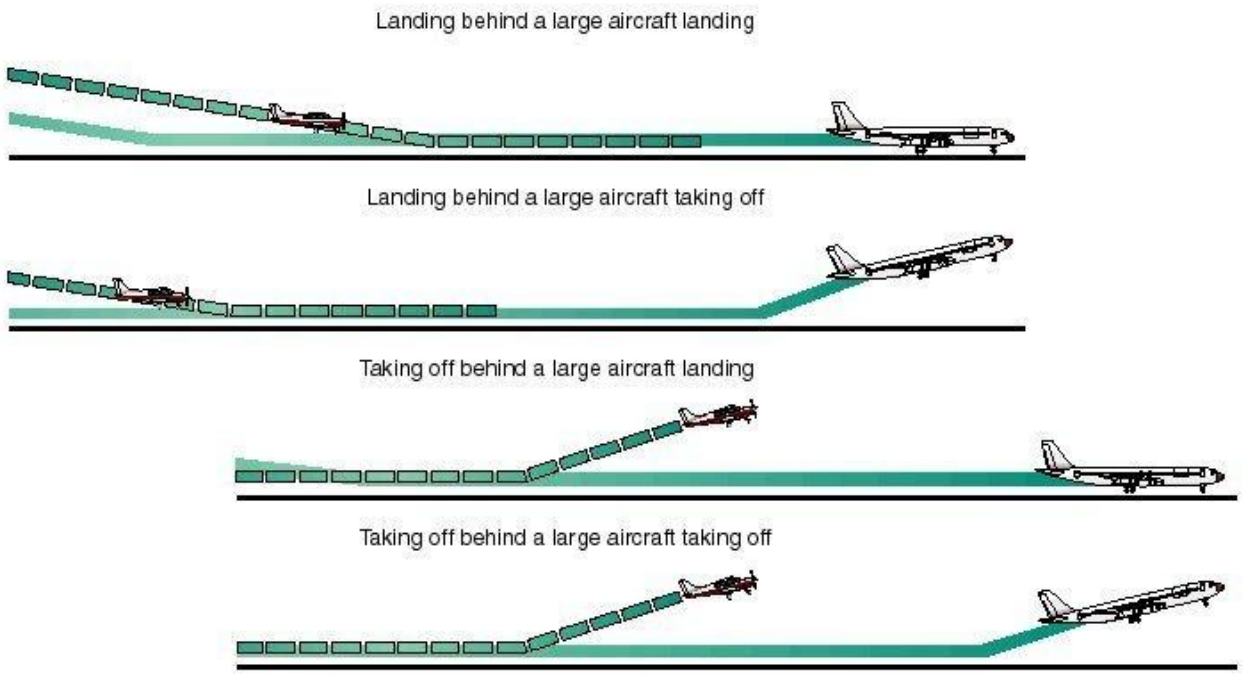
Wake Turbulence

- Wingtip vortices created when lift is generated
- Intensity depends on
  - Aircraft weight
  - Speed
  - Configuration
- Large, heavy aircraft, low speed, high angle of attack = greatest wake turbulence
- Can induce uncontrollable roll rate for small ac

Wake Turbulence

- Wingtip vortices sink below the flight path of the aircraft which generated them
- Most dangerous during a light, quartering tailwind condition – can move the upwind vortex over the runway, forward into the touchdown zone
- Can bounce 2x as high as wingspan of ac
- ATC provides separation unless you accept clearance to follow aircraft in sight

Avoiding Wake Turbulence



Jet Engine Blast

- Hazard for small aircraft behind aircraft with jet engines
- Stay several hundred feet away

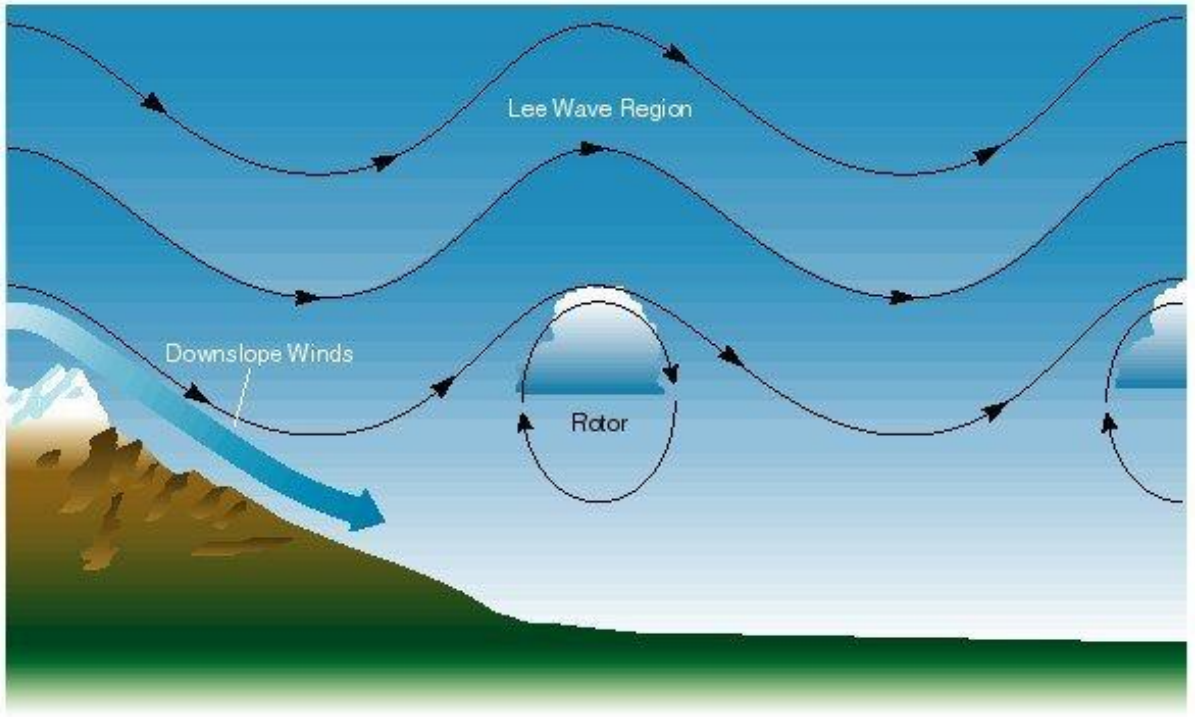
Clear Air Turbulence (CAT)

- Usually above 15,000’
- No visual warning
- Can be present in non-convective clouds
- Often develops around jet stream (narrow band of high winds near tropopause)
- Usually thin layers

Mountain Wave Turbulence

- Stable air crosses mountains – smooth on windward side
- Wind 40 knots or greater, perpendicular to ridge
- Waves extend 100 miles or more downwind
- Crests can be well above highest peaks
- Violent turbulence

Mountain Wave Turbulence



Mountain Wave Turbulence

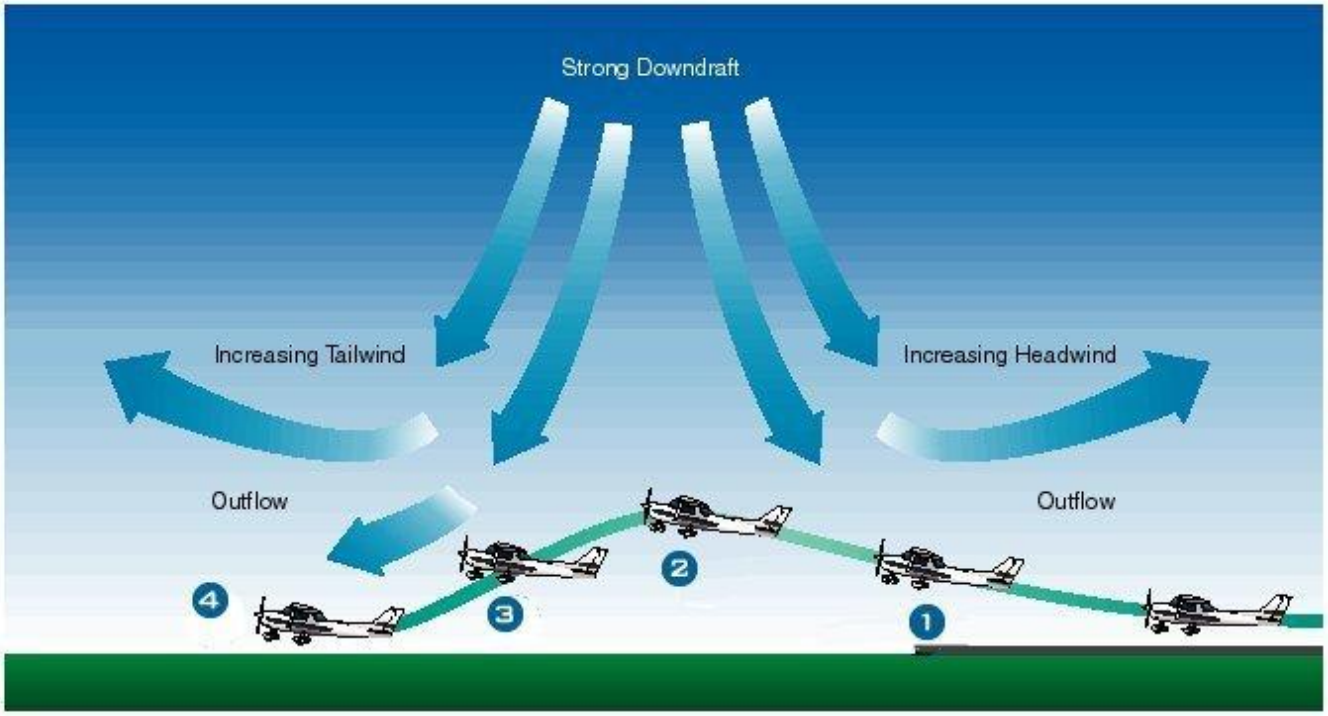
- Signature clouds
  - Rotor clouds form below crests of waves
  - Lenticular (standing lenticular) form in the crests
    - May contain 50 knot winds
  - Cap clouds form over the mountains
- Approach at 45º angle
- If winds at altitude exceed 30 knots, FAA recommends against light aircraft flying over mountains

Wind Shear

- Sudden, drastic shift in speed/direction, in vertical or horizontal plane, any altitude
- Associated with:
  - Frontal system
  - Thunderstorm
  - Temperature inversion with strong upper-level winds
  - Clear air turbulence
  - Convective precipitation
  - Jet stream

Microburst

- Horizontal – one n.m. or less
- Vertical – 1,000’



LLWSAS

- Low-level Wind shear alert systems
- Wind sensors placed at several places around airports
- Wind differences evaluated by computer
- Alert given when wind shear detected
- ATC will give you the readouts of two or more sensors

TDWR

- Terminal Doppler weather radar
- Uses narrower beam
- Better picture of thunderstorms

Visual Indications of Wind Shear

- Rain shaft
- Virga
- Dust ring on ground

Icing

- Visible moisture necessary for structural icing
- Freezing rain gives highest rate of accumulation
- Temperature of aircraft surface 0ºC or less
- Effects:
  - Thrust reduced
  - Drag and weight increased
  - Lift decreased

Types of Ice

- Rime ice
  - Stratus clouds
  - Tiny super cooled droplets
  - Trapped air – gives opaque appearance
  - Changes shape of airfoil, destroys lift
  - On leading edge of airfoils
  - Temps -15ºC to -20ºC

Types of Ice

- Clear ice
  - In areas of large supercooled water droplets
  - In cumulus clouds or freezing rain under warm front inversion
  - Flow over the structure, slowly freeze
  - Glaze the surface
  - Most serious form of ice – adheres, difficult to remove
  - Temps 0ºC to -10ºC

Types of ice

- Mixed ice
  - Combo of rime and clear
  - Temps -10ºC to -15ºC

Restrictions to Visibility

- Haze – fine dry particles, stable atmosphere, light winds, visibility good above layer
- Smoke – combustion particles, reddish or orange sky
- Smog – combo of fog and smoke, stable air and terrain may trap smog and make worse
- Dust - fine particles of loose soil, strong winds, unstable atmosphere

Volcanic Ash

- Highly abrasive
- Pit windscreens and landing lights
- Can clog pitot-static and ventilation systems
- Can damage control surfaces
- Jet engines more likely to be severely damaged than piston
- AVOID